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STRUCTURAL GEOLOGY OF THE MIDDLE YANG-TZÏ-KIANG GORGES

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During the first half of the year 1904 I made an exploration trip in the province Ssï-ch'uan of West China, which I reached by going up the Middle Yang-tzï-kiang from I-ch'ang to Chung-king. The results of this journey are published in the *Revue Universelle des Mines* (1906), of which a separate edition[1] also appeared. The reason why I now return to this subject is to compare my results with those obtained by Messrs. Bailey Willis and Eliot Blackwelder, who—and this is a curious coincidence—reached I-ch'ang on the same day (June 9, 1904) as I did, after our travels in China. To my regret this coincidence did not lead to our meeting, either at I-ch'ang or on board the steamer to Hankow. Their researches and personal views were published in the splendid work, *Research in China*, under the auspices of the Carnegie Institution of Washington, in April, 1907.

In this description of the structural geology of the Middle Yang-tzï-kiang[2] I shall go much more into details than in my publication about the Red Basin. On the other hand, I shall only cursorily describe the encountered formations and not enter into the peculiarities of the separate strata. In contrast to my former description I shall not this time mention my observations in an upriver direction, but in a downstream one, this manner having the advantage, as we shall presently see, that the windings of the river can be explained in detail from the geological structure of the country.

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[1] *Géologie du Bassin Rouge de la province Se-Tchouan en Chine.*

[2] The accompanying map has been put together, as far as topography is concerned, from those of Arthur Kniep and R. H. Sargent.

From K'ui-chóu-fu to I-ch'ang the Yang-tzï flows, for a distance of 135 km. through the ranges of mountains bordering the Red Basin of Ssï-ch'uan. Formerly I have already observed that the anticlines, which in the Red Basin strike almost NNE–SSW, are bent round in the north and east toward the NE, ENE, and E. To explain this, I assumed that the Red Basin had been forcibly pressed up against the old mountain ranges of Kuen-lun and Tsin-ling-shan trending in almost equatorial direction. The trends in these border ranges of the Red Basin do not therefore conform to the normal in the basin itself.

From K'ui-chóu-fu to I-ch'ang the Yang-tzï-kiang cuts the following formations:

1. A granitic formation intersected by numerous dykes of granite, diorite,[1] and melaphyre, all of them striking almost N–S.
2. Metamorphic schist, consisting of hornblende, chlorite, and mica schists, alternating with layers of nearly pure quartz.
3. Purplish-brown limestone with fossils, among which is a coiled nautilus, which, according to Professor Frech, of Breslau, marks the Lower Silurian. The most striking are, however, the numerous and very large casts of Orthoceratites. This is, I believe, the Cambro-Ordovician Ki-sin-ling limestone of Blackwelder and Willis.
4. Green shales of about 900 m. thickness; this the Middle Paleozoic Sin-t'an shale of the afore-named gentlemen.
5. The gorges-limestone formation, 1,600 m. thick, called by the two other explorers Wu-shan limestone.

As, according to my researches, not only a part of the Wu-shan gorge but all the gorges are built up of this formation, I consider the name gorges-limestone better than Wu-shan limestone. This formation is considered as belonging to the "Upper Carboniferous" by said gentlemen.

What Blackwelder comprises in the K'ui-chóu series, has been divided by me as follows:

6. The reddish-brown sandstone and argillite formation, 300 m. thick.

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[1] Under these names are comprised various kinds of aplitic and lamprophyric "Ganggesteine" of granito-dioritic character.

7. The slaty limestone formation, 300 to 400 m.

8. The sandstone formation, with layers of coal, whose flora belongs to the Rhetian, 600 m.

9. A formation, 1,800 to 2,500 m., of alternating strata of sandstone and argillite, the former of which are generally of eolian origin. This has been named by me the K'ui-chóu formation.

Between 8 and 9 there is, in the middle of the Red Basin, a series of marls, 50 m. thick, but this is lacking in the bordering part.

The formations 7 and 8 I believe I may count as belonging to the Permian or to the Lower Triassic, and to the Upper Triassic.

The stratum between 8 and 9 seems to belong to the chalk formation, so that the K'ui-chóu formation, in which I did not find any organic remains, may be considered as belonging to the chalk formation, and, taking into account the thickness of the formation, it might be assumed that the deposit continued into the Tertiary Period.

The folds of the Red Basin of Ssï-ch'uan are of later date than the K'ui-chóu formation. As latest formation must be named the following:

10. A conglomerate bank, which I have encountered in several parts along the Yang-tzï-kiang. The bowlders and pebbles in this conglomerate generally are of eruptive origin whereas the cement consists of a calcareous siliceous tufa. This must therefore be the latest formation, whose origin dates after the folding of the Red Basin.

We will now describe the structural geology of the Middle Yang-tzï-kiang gorges going downstream from K'ui-chóu to I-ch'ang. Coming from the synclinal area, west of K'ui-chóu-fu, the Yang-tzï for the first time encounters the high gorges-limestone mountain ranges, to the east of that place. On the left bank the river tries to penetrate the softer upper strata so that a creek is formed there. But as the softer layers, which formerly spread out like a mantle over the anticlinal gorges-limestone mountain range, and nowadays have been washed away from the crests of this range, still, as a whole, form a kind of dam, the Yang-tzï is forced to make a bend toward the first of the great gorges: the Fong-hiang-hia or gorge of K'ui-chóu-fu. This gorge being a deep incision of the big river through the mountain range east of K'ui-chóu-fu, clearly shows its structure.

The gorges-limestone strata strike about ENE–WSW and dip

40° WNW. The river narrows considerably and the banks at once rise to double the height of what they were outside the gorge. Soon the dip decreases to 25°, and in the deeper levels of the formation to 7° or 8°. Now soon follows the anticlinal flattening of the layers, and after a pretty long distance with the strata in horizontal position the southerly inclined limb also makes an angle of 7° to 8°. This is a broad and low fold. Suddenly the strata, with a faint southerly dip, bend round sharply and get a northerly dip, and now the layers rise to the south under an angle of 70°. This time the anticlinal folding follows much sharper, and the southern limb dips 75° south. In both limbs, and in the crest of the anticline itself the layers are not straight, but waved, and show many secondary plications. All this points to a strong compression and forcing outward of this anticline.

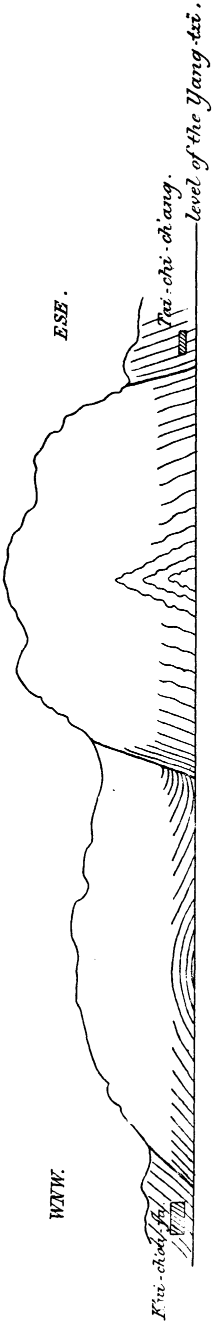

Fig. 1

The structure of this first limestone mountain range as it appears in the gorge of K'ui-chóu-fu, therefore, is that of two folds strongly pressed together, each of which takes up just one-half of the length of the gorge on the river level (see Fig. 1).

As soon as the river, a little way above Tai-chi-ch'ang, issues from the gorge, it re-obtains a double width in the syncline area of Wu-shan. To the north and to the south the river is inclosed by the lofty gorges-limestone mountains, and the next gorge is already perceptible in the range south of the Yang-tzï. In this syncline nothing is left of the later formations but the reddish-brown and the slaty limestone formations, with a slight relic of the sandstone formation. It is a strongly compressed syncline, by reason of which compression a commencement of dynamo-metamorphosis is observable, especially the reddish-brown formation, recognizable by the far greater hardness of its sandstone layers, and, besides that, by their becoming slaty on account of the greater amount of mica they contain.

In the following description of the different strata and their position in the synclinal area of Wu-shan, I must neglect details and shall merely describe the structure in general features.

The Yang-tzĭ, which in the K'ui-chóu-fu gorge flowed almost vertically to the trend of the strata, downstream Tai-chi, transects the reddish-brown and the slaty limestone formations which also dip SSE, and, after a wedge-like compressed syncline, it strikes against the 25° NNW-dipping limb of the anticline south of the river. This causes the river near K'ui-ché-pan to bend from its ESE course into a NE direction. In this part the layers are much disturbed, and a relic of the sandstone formation is found among the slaty limestones. Near Tan-tia-wan the river has again gone too far north and has abutted, in steeply SSE-dipping layers, against the southern limb of the northern anticline. The river is now again forced to bend, and flows in a WNW direction through the strata of the slaty limestone formation, which, at first dipping faintly SSE, soon becomes almost horizontal, and then again dips 50° NNW; and lastly the river forces its way into the reddish-brown formation, which also dips precipitously north. Near Wu-shan the river has thus, for the second time after Tai-chi, entered the northern limb of the southern anticline, which it has again transected in a gorge just below Wu-shan.

Before describing this gorge, being another magnificent section through a high mountain range, I will just discuss the profile of the Ta-ning-ho, a tributary river, which flows into the Yang-tzĭ near Wu-shan. Going in a NNW and N direction from Wu-shan, along very hilly territory, in whose narrow synclinal valleys I only found relics of the reddish-brown and of the slaty limestone formations, I reached the place Ta-ch'ang or Kiu-shĭ-li-p'u on the Ta-ning-ho. This swift narrow mountain stream I followed to its confluence with the Yang-tzĭ. Owing to the imposing gorges through which we passed, and to the remarkable skill and proficiency in navigation with which the skippers of the river craft guided their boats over rapids and along an almost rectangular bend in the river, where the current set straight upon the steep cliffs, this was certainly one of the finest and most stirring of my water trips in China. The rapids are generally formed in synclinal territory by bars of bowlders; here the river is broad and its banks are generally lower. Only once there was a fall of a few feet in the bed of the river itself. In the limestone gorges the river is much narrower and confined between high steep cliffs.

My observations there coincide pretty well with those of Willis and Blackwelder. On pp. 277, 278 of their work[1] they say: "Along the Ta-ning-ho the red series seems to be devoid of coal which may lie higher in the system than any strata remaining in those synclines." As I have already observed before, there only remain in these synclines the strata that lie far below the sandstone formation with its layers of coal.

Ta-ch'ang is situated in a rather wide synclinal area. If we go down the Ta-ning-ho, a very winding river, along whose course many pebble banks form small rapids, we reach after a sharp bend the first gorge, the Lao-men-hia.[2] Here again the gorges-limestone strata is folded up in an anticline of which the northern limb dips steeply and the southern limb but faintly. It took us a little more than an hour to pass this gorge. During twenty minutes we next float down through a synclinal, more open area, with a dangerous rapid, which leaves but a narrow passage-way between banks of pebbles; and then we reach the next gorge, which exposes two lower folds pressed together. The southern limb of the second of these folds dips 20°–30° SSE. The gorge, called "Lung-chin-hu-cho-hia," or "gorge of the dragon and tiger," is passed in fifty minutes. Sin-t'an-hia[3] is situated at the lower end of the gorge, which again opens on a second synclinal area, in which the river makes almost a loop. Here again was a very difficult rapid, at least when the water is at the height encountered by me. The next and fourth anticline is less broad, and then, after a short synclinal area, there again follows a gorges-limestone anticline, in which the now very swiftly flowing Ta-ning-ho has excavated a narrow gorge. To reach this gorge we had to pass a very difficult rapid, just at a place where the river made a rectangular turn. This too was negotiated with remarkable skill by the two steersmen standing, the one fore and the other aft; these two men and myself being the only members of the party to remain on board the sloop, the others preferring to walk along the river banks.

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[1] *Research in China.*

[2] Old Gate Gorge.

[3] Literally, New Rapid Gorge.

These last two anticlines must be considered as the easterly prolongation of those of the gorge of K'ui-chóu-fu. We see that these two anticlines, having diverged east of K'ui-chóu-fu, have got limbs of almost equal dip, and have therefore become lower from west to east, especially the southern one.

It takes nearly two hours to go down stream from Sin-t'an-hia to the lower end of the last gorge and twenty minutes more through the synclinal area to Wu-shan.

From K'ui-shï-li-p'u to Wu-shan five anticlines with an almost equatorial direction, which lie close together, are thus transected by the Ta-ning-ho. Just below Wu-shan the Yang-tzï makes a bend like the one below K'ui-chóu-fu, and leaves the steeply NNW-dipping reddish-brown formation, to enter the 80° NNW-dipping gorges-limestone formation. In this second of the grand gorges of the middle Yang-tzï the river flows at first almost in the trend of the layers, only gradually reaching deeper levels. This already points to the sinking of the anticline, to which this limb belongs, viz., in an easterly direction. Just upstream before the hamlet Klao-che, the river, which in this part of the gorge has but slightly narrowed, enters the underlying formation, the olive-green Sin-t'an shale, of which the upper part is brownish red. We now perceive on the left bank a very fine dome[1] in the gorges-limestone formation, below which the observed Sin-t'an shale are situated (see Fig. 2). We also observed that from west to east the Sin-t'an shale remains much lower, which also points to a sinking of the anticline toward the east. After having for a short distance transected the southern limb of this anticline in the gorges-limestone, below Wen-che-chi we find very markedly plicated layers in the same formation, which eventually dip 65° NW near Sui-che-t'an. The Yang-tzï is bent round to the SSE and cuts almost vertically the next anticline, the upper strata of the northern limb of which are, as just mentioned, strongly compressed. The NW dip of the layers at first increases to 80° and then diminishes to 25°. And then the anticlinal arch in both of the limestone walls becomes beautifully visible. This very fine section, in the middle of which the two limbs of the anticline, both dipping 25°–30°, are most clearly exposed, stretches over almost the whole length of the SSE-directed course, in which the narrow Yang-tzï flows below Wen-che-chi. In the last part of the SE limb the layers dip 70° south.

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[1] Willis and Blackwelder, *op. cit.*, Vol. I, p. 287: "Northwest of the grand arch of the Wu-shan limestone, probably one of the most superb exposures of a fold in the world, the K'ui-chóu red beds occur in the syncline, and the Yang-tzï valley is developed in them for some miles westward." From the above it is clear that in this case under the K'ui-chóu red beds must be understood the reddish-brown and the slaty limestone formation, but not the proper K'ui-chóu series.

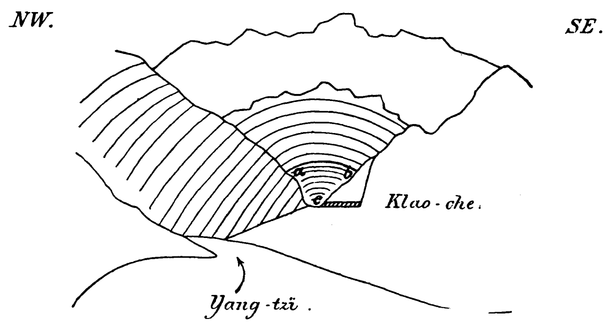

FIG. 2

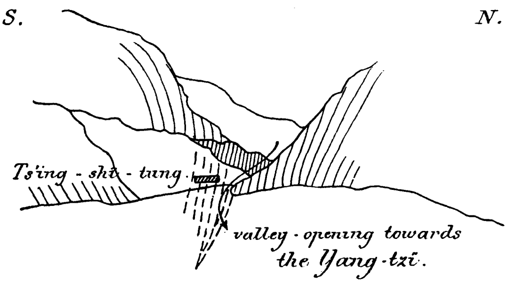

FIG. 3

Near Ts'ing-shï-tung the Yang-tzï turns sharply to the east, and flows through the eastern continuation of a valley, formed by a wedge-shaped syncline (like that reproduced in Fig. 3). Inside the valley looking west, we could see a series of south-dipping layers of the reddish-brown formation, but soon below Ts'ing-shï-tung the river banks are formed of 50° to 55° north-dipping layers of gorges-limestone, which shows that the river, emerging from the wedge-formed connection of the two anticlinal limbs, has pierced into the northern limb of a southern anticline, which, in this part, trends nearly EW. From Ts'ing-shï-tung to Fu-li-chi, the Yang-tzï remains in the upper part of the gorges-limestone formation, which causes the river to become broader and the banks, especially the left bank, less high. The right bank rises much higher, according to the dip of the layers toward the north. Before Pei-chi the gorges-limestone limb bends slightly toward the SE, visible by the NE dip of the layers. After a short transversal fault, the EW trend of the anticline reappears. Before a cleft in the river bank near Leng-sui-chi, where the layers show many plications, a bar of stones has been formed, and in the gorge itself there is a small rapid, a thing which is very rare in the gorges. A little farther on, we see in front of a cleft in the left bank a bar, formed by many reddish-brown and gray pebbles, which reveals the existence, to the north of the river, of a synclinal area of the reddish-brown formation. In fact, I found to the north of Fu-li-chi, the reddish-brown, and also part of the slaty limestone formation, with very slaty layers, caused by the strong compression of the narrow syncline. These show, especially in the slaty limestone, all the colors ranging from reddish-brown, orange, yellow, and olive green to grayish-blue. Just before Fu-li-chi there again appears in the mountains to the south of the Yang-tzï a fine dome, standing almost vertically on the river, which thus points to the existence of a third anticline (see Fig. 4). Below Fu-li-chi, till Nan-mu-yüan, the river again penetrates the deeper levels of the gorges-limestone formation. The secondary plications accompanied by small faults, are continued in the layers, which have a general EW trend and dip 60° N. Below Yang-chi-p'ong the river, which was flowing ESE and E, turns to the NE. For this fact we soon find the explication in the NW-dipping layers, which therefore point to a turning of the anticlinal axis from an EW to a NSW–NE direction. In this latter portion of the gorge the layers show many small secondary folds and faults, while to the south of the Yang-tzï, in the higher mountains, once more an indication of the anticline is given in the layers that are bent round to a horizontal position. At last, near Kuan-tu-k'ou, we emerge from

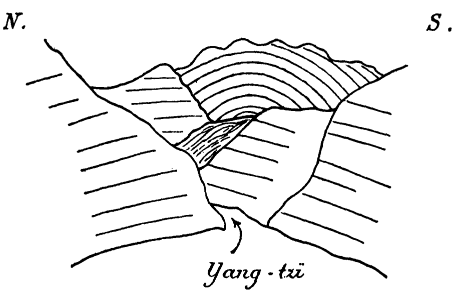

FIG. 4

the 45 km. long Wu-shan gorge, through layers, dipping rather steeply N, of the upper levels of the gorges-limestone which show a turning of the anticlinal axis toward W–E.

To recapitulate we see that as far as the Wu-shan gorge exposes the structure of the mountain range south and east of Wu-shan, this range appears to be formed by three anticlines, closely pressed together. Of these the anticline farthest upstream rises highest, for in that we see the green slaty formation underlying the gorges-limestone formation. (Fig. 5 gives a sketch of my conception of the geological structure of this gorge.) The Yang-tzï has cut its course quite through the northern two anticlines, and then through part of the northern limb of the southernmost one.

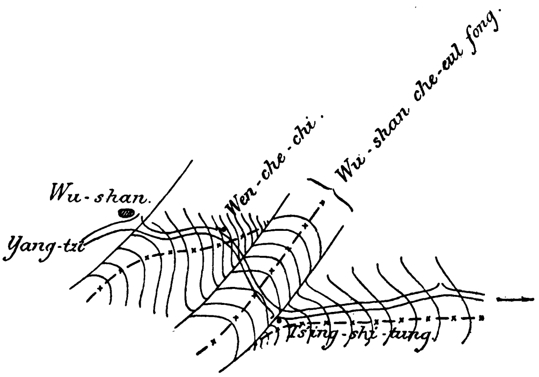

FIG. 5

From the above it will appear that my observations, which were taken while going upstream, at the rate of 25 km. a day, differ in many particulars from those of Willis, which were taken during the so much swifter course downstream.

The principal difference is, that Willis considers a great part of the Wu-shan gorge to be formed of Ki-sin-ling limestone, while I maintain that nothing but the gorges-limestone, Willis' Wu-shan limestone, appears in that gorge.

Willis writes: "Below Nan-mu-yüan the base of the Wu-shan limestone is marked by the occurrence of black cherts and it may be assumed that the Sin-t'an (middle Paleozoic) shale occurs in its proper place below the limestone, but we did not see it."[1]

From what I have written above, it appears, that the thick Sin-t'an shale formation was not observed by me either in that place, although it would have been almost an impossibility to overlook it (had it been there) going, as I did, so slowly upstream. Besides, in connection with the rest of my researches, it could not be expected to occur there. Willis continues:

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[1] *Op. cit.*, Vol. I, Part 1, pp. 286, 287.

> Between Nan-mu-yüan and Wu-shan-hien the Yang-tzï flows across a sequence of smaller and larger folds, chiefly of the Ki-sin-ling limestone, but, at the head of the gorge, consisting only of the Wu-shan limestone. The sequence will best be understood by reference to the section [see his Fig. 61], which was sketched, as we floated past the magnificent cliffs in which it was exposed. As we could not measure distances, the distribution along the river was noted and has since been adjusted to "Chevalier's map of the Yang-tzï." Two anticlines and a syncline bring the top of the Ki-sin-ling limestone high above the stream, above and below Nan-mu-yüan. For several miles below Ts'ing-shi-tung the course is in the axis of a carinate syncline, a position determined by the Sin-t'an shale, although the canyon is now sunk below that formation in the Ki-sin-ling limestone. The thin beds of the latter dip very steeply, but above them, in a nearly flat position, the Wu-shan forms the upper cliffs. From half a mile above Ts'ing-shï-tung the synclinal valley extends westward but it is occupied only by a small tributary. The lower part of the Wu-shan gorge is cut across a great anticline of the Ki-sin-ling, the arch extending up to the mountain tops 3,000 feet or more above the river. The inner part of the anticline in the thin-bedded strata, near the base of the formation, is therefore exposed along the water level, and is seen to be characterized by many sharp folds and possibly by minor overthrusts. The details could not be followed as we passed, but the major structure was clear. Finally, toward the west, the dip is continuous on the northwestern limb of the arch, and the Sin-t'an shale comes in above the limestone.[1] The shale is overlaid by the Wu-shan limestone with characteristic black chert of the lowest beds. There is a repetition of the shale and limestone with black chert, occasioned by a slight overthrust at this horizon of adjustment, and then follows the mass of the Wu-shan limestone forming the upper part of the Wu-shan gorge.

We see that this description differs very materially from my researches. In confirmation of my own views I must remark that it is far more difficult to take careful observations while going rapidly downstream than during the slow course upriver. I myself experienced this on my return journey.

If we now continue the course of the Yang-tzï, below K'uan-tu-k'ou, it will appear that an ever-widening synclinal area is occasioned between two anticlines, viz., the middle anticline of the Wu-shan gorge with its NE–SW trend, which in the NE is probably bent ENE–WSW, and the almost true equatorial trend of the southernmost of the three anticlines of the Wu-shan gorge. In this synclinal area occurs for the first time downstream since K'ui-chóu-fu besides the reddish-brown and the slaty limestone formations, the sandstone formation and that of K'ui-chóu-hien. After K'uan-tu-k'ou the Yang-tzï, much wider now, flows through a narrow ENE–WSW trending syncline, in the reddish-brown and the slaty limestone formations, until upstream from Wan-h'ou-two, it strikes a 30° south-dipping limb, and so again is turned toward the east and the southeast. Another bend in the trend of the layers is also observable in their dip. From the south-dipping layers the river is headed into north-dipping ones, which again become NE-dipping, the layers being thereby much fractured. Before Pa-tung-hien the dip is again toward the north and then northwest. Just below Pa-tung-hien the Yang-tzï cuts across the upper part of a local fold in the gorges-limestone formation, thus showing in the right river bank the section as represented in Fig. 6. It is still the same north-dipping limb of the most southerly Wu-shan gorge anticline; and the layers, dipping consecutively NW, N, and NE, plainly reproduce the fold in the limb.

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[1] This was not observed by me.

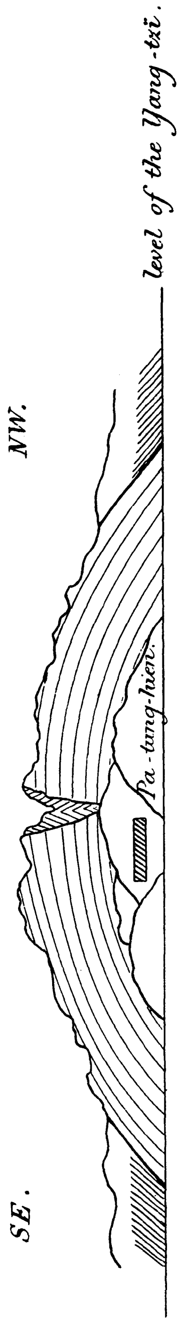

Fig. 6

The Yang-tzï then continues its way in the 30°–40° north-dipping layers of the reddish-brown formation, trending ESE–WNW, and then in the slaty limestone formation, which here has much diminished in thickness and individuality. Near the Niu-k'ou-t'an the river reaches the base of the sandstone formation, consisting of dark-green slaty sandstones. The river now flows almost in the trend of the layers.

Near Pa-t'ou-t'an, the right bank consists of the reddish-brown formation, above which still lie a few slaty limestone beds; the left bank is of the sandstone formation, overlying which soon appears the K'ui-chóu-hien formation. Near Che-men then we see on the right bank the reddish-brown, on the left the sandstone and K'ui-cóuh formations.

We must observe the thinning out of the slaty limestone formation. A little farther downstream we see the layers to the right dipping south, and those to the left dipping north, and this fold goes from the right bank to the left just above the Yeh-t'an. This fold occurs in the reddish-brown formation, and thus we have come out of the northern limb into the anticline itself. It we now consider that the same anticlinal crest, which, a little above Fu-li-chi, was estimated at a height of some 500 m. in the gorges-limestone formation (Fig. 4) was at a height of 10 m. near Yeh-t'an in the stratigraphically much higher reddish-brown formation, then the conclusion is patent, *that this anticline of Pa-tung* (as I shall call it) *has greatly diminished in height from west to east.*

The sandstone formation near Yeh-t'an contains layers of coal, as is the case in the Red Basin itself. It rests on the fold in the reddish-brown formation and supports the K'ui-chóu layers. Immediately below the Yeh-t'an the fold commences to turn toward the south, and, going downstream, we find the NNE-dipping limb of the sandstone formation, to which soon succeeds the K'ui-chóu formation, trending already SE–NW with a dip NE. In the thick sandstone beds, about ten in number, of the K'ui-chóu formation which appear typically, especially on the left bank till close to K'ui-chóu, we see how the trend gradually becomes NS and the dip 60° east. This plainly shows *the deviation of the anticline of Pa-tung, which in general traits has an equatorial direction, to a meridional one, the convex side of the bend being turned toward the NE.* The significance of this deviation I have set forth on pp. 180, 181 of my *Géologie du Bassin Rouge*, where I wrote:

> Another deviation was observed upstream from K'ui-chóu; it is the one, to the south, of the anticline which extends from the middle of the Wu-shan gorge in a more or less equatorial direction toward the east. This deviation must have been caused by the powerful anticline of Nan-t'ou, about which later.

And again on p. 190:

> I must finally assume that the anticline of Nan-t'ou must have formed the line of resistance for the anticlines of the Red Basin, which, in its NE part trend

ENE–WSW. Very interesting in connection with this appears the deviation of the anticline, which extends from the middle of the Wu-shan gorge toward the east. This deviation takes place a little farther upstream, above K'ui-chóu, from a direction about EW to a more or less meridional one, so that the convex side is turned toward the NE. This fact shows, firstly, the capacity of resistance of the anticline of Nan-t'ou, which resistance would seem to me impossible, if a great fault[1] really existed. And, secondly, that the origin of the anticline of Nan-t'ou must date from before the folding of the Red Basin.

According to my idea the sinking from west to east and the deviation of the anticline of Pa-tung, have in the structural geology of the land, a very special and interesting signification, representing as they do the relation of a fold of the Red Basin with regard to the anticline of Nan-t'ou.

This deviation of the anticline of Pa-tung has not been observed by Willis. Pumpelly however does mention it, although this explorer also failed to observe its signification. Pumpelly[2] writes:

> The trend of the beds, which near the gorge (of Mi-t'an) was NNE, with a dip of about 40° to WNW, changes here to N with a dip to E and farther up opposite Kwei (K'ui-chóu-hien) it is N by W with an inclination of 70° E by N. Here is the beginning of a series of those angular plications so common to coal measures in all countries. Small beds of limestone and red argillite alternate with sandstone until, about two miles above Kwei, the first coal seems to crop out and with the appearance of these, the trend changes to NW by W, more than 90° from its normal direction of NE–SW.

If we look at the hills of the K'ui-chóu formation near K'ui-chóu, we see (as Fig. 7 shows) for the last time the indication of the Pa-tung anticline through steep ENE-dipping layers on the left bank of the Yang-tzï, by the beginning of the anticlinal arch in the top of the massive hilly landscape at the place, and through steep WSW-dipping layers in the hindmost hill-tops on the right bank of the river.

Below K'ui-chóu the trend of the layers is NNE–SSW, and the dip still steep ESE, but this soon becomes less, and it coincides with a decrease in height of the surrounding hills. Neither do the hard sandstone beds occur in the upper levels of the K'ui-chóu formation.

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[1] This remark refers to my observation of the anticline of Nan-t'ou, in contrast with von Richthofen's *Gebirgsbruch bei I-tsch'ang*. Willis too remarks (p. 286 of his work): "von Richthofen was thereby led to consider it a fault-scarp, but there is no fault such as he inferred."

[2] *Smithsonian Contributions to Knowledge*, Vol. XV, "Geological Researches in China, Mongolia, and Japan," p. 6.

Near Lao-K'ui-chóu, a deserted place, on the right bank, we are in the synclinal area and then soon follow 45° WNW-dipping layers, and the river again enters into the levels of the K'ui-chóu formation, which here, however, do not contain so many sandstone beds as in the western limb of the syncline.

We must therefore remark the thinning out of the hard sandstone beds of the K'ui-chóu formation from west to east. And they no longer crop out so typically from the river banks as above K'ui-chóu-hien. Under the K'ui-chóu formation the river penetrates the slaty sandstone layers of the sandstone formation, which has here greatly diminished in thickness and does not contain any coal measures.

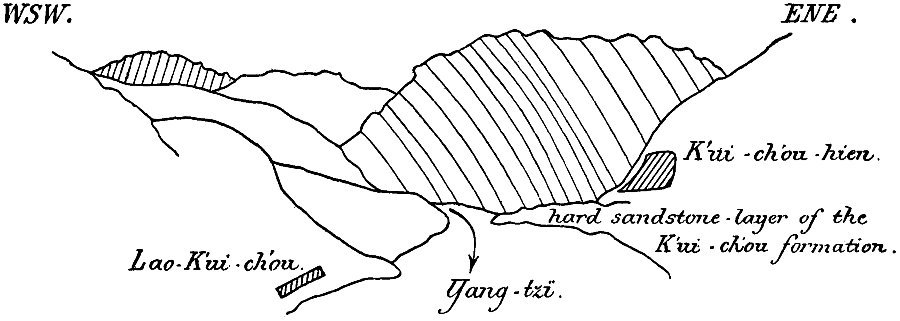

FIG. 7

We must observe the thinning out of the coal layers in the sandstone formation, and the thinning out of the formation itself toward the east.

Directly beneath the sandstone lies the gorges-limestone formation, which, rising up in an anticlinal limb, has again been transected by the Yang-tzï in a magnificent and grand gorge.

We therefore observe that the reddish-brown formation is also thinned out toward the east.

In the Mi-t'an gorge the Yang-tzï cuts across 30° to 40° WNW-dipping layers of the gorges-limestone formation. The massive mountains rise to more than double the height of these in the preceding sandstone area of Hsiang-chi. Only there, where a softer slaty layer complex occurs in this formation, we find a small valley on both sides of the river. This same layer complex, we shall see, plays an important part in the direction of the course of the Yang-tzï in the

I-ch'ang gorges. In the Mi-t'an gorge we see before us a west-dipping limb of the gorges-limestone formation, beneath which appears the green shale formation, "Blackwelder and Willis' Sin-t'an shale."

Between the Mi-t'an and Niu-kan-ma-fei or Ox-liver gorges, we find the Sin-t'an area. In about the middle of this area, which is bordered in the W, S, and E by the high gorges-limestone mountains, occurs the low and sharp fold of Lung-tchoe of which a photo appears on p. 43 of my publication on the Red Basin. This fold which has a 45° W-dipping and a 10° E-dipping limb, *itself dips steeply south* (see Fig. 8). It exposes a reddish-brown limestone, in which I found lower Silurian nautili, and many fine and very large Orthoceratite casts. I therefore believe that this must be the same limestone as the Ki-sin-ling limestone of Blackwelder and Willis. On this limestone rests the green shale formation (Sin-t'an-shale) and above that the gorges-limestone formation. All this as far as the right bank is concerned. On the left bank, on the contrary, the Ki-sin-ling limestone rises to much higher levels, and we find under the reddish-brown limestone a crystalline dark blue one, in layers, that are often separated by several centimeters, as a result of the plication. The closing of the narrow Sin-t'an basin by the gorges-limestone formation was not observed by me toward the north, looking from the right bank. We must still mention that, on the north bank, occurs, on top of the horizontally cut off and W-dipping Sin-t'an shales a thick conglomerate bed with large rounded-off pebbles, which must be originally from the valley in the north. This bed is of a recent date and was formed after the plication of the Red Basin, and while the Yang-tzï was cutting its way deeper and deeper into the mountains. In the eastern limb of the fold of Lung-tchoe the green Sin-t'an shale formation contains more hard quartzy sandstone beds than in the western limb. The formation also diminishes in thickness in that direction. The incline of the layers decreases and the Yang-tzï again enters the

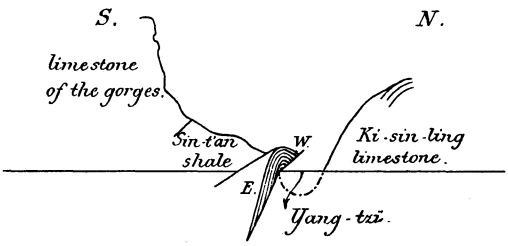

FIG. 8

overlying limestone formation, rising to mountain-heights, in which is cut the Niu-kan-ma-fei-hia.

In this gorge the dip of the layers soon again becomes W, and so, going down-stream, we find ever deeper levels, until, immediately after the end of the gorge near Miao-ho, the green shales reappear, but now in very much thinner beds.

This shale formation (Sin-t'an shale) thins out, in the western limb of the anticline of Nan-t'ou, from west to east.

The Ki-sin-ling limestone, which was exposed by the fold of Lung-tchoe, in the Sin-t'an area, does not again show itself east of the Niu-kan-ma-fei-hia.

As Blackwelder and Willis have observed in the upper course of the Ta-ning-ho the Sin-t'an shale to be in conformity with the Ki-sin-ling limestone, so that this limestone formation appears to extend as far as Sin-t'an, the thinning out of both formations toward the east would increase the signification of age of the anticline of Nan-t'ou. More about this later.

About the geoglogical structure of the Niu-kan-ma-fei-hia or Lu-kan gorge and the Mi-t'an gorge Willis again gives a description greatly differing from my own. He writes:[1]

> The Lu-kan gorge is a canyon across the Ki-sin-ling limestone, which dips NW. Above Sin-t'an the overlying middle Paleozoic shale, which we have named from its occurrence at this point, is succeeded by the Wu-shan limestone, dipping 40° NW and giving rise to the Mi-t'an gorge.

I presume that while going so swiftly downstream the fold of Lung-tchoe was overlooked, and so the whole structure was wrongly interpreted. According to Willis, a deep valley would have to occur between the two limestone formations. The photo on p. 43 of my *Géologie du Bassin Rouge* shows instead of a valley a high mountain range of gorges-limestone.

At the lower end of the Lu-kan gorge the trend of the layers is NNW–SSE. Underlying the but slightly developed green shale formation appear the crystalline schists, which trend NS and dip 20° W. They consist of mica, chlorite, and hornblende schists, alternating with nearly pure quartz beds and intersected by dykes of melaphyre. Near the lower opening of the Lu-kan gorge (Niu-kan-

[1] *Research in China*, Vol. II, Part 1, p. 286.

ma-fei-hia) there occurs a broad dyke of dioritic "Ganggestein" straight across the river, which, having left, by incomplete river-erosion, a couple of cliffs in the river bed, has caused the Kung-ling-t'an (a dangerous rapid).

A little way upstream from Mei-lin-to this crystalline schist formation stops, and it becomes apparent that it overlies a granite formation. The granite extends in a range of low rounded-off cliffs to the I-ch'ang gorge and northerly as far as one can see. Toward the south, however, we see the gorges-limestone mountains, which overlie the granite, stretching in one angular but continuous line to the next gorge.

This fact, taken in connection with a like occurrence in the Sin-t'an area, makes me draw the conclusion that there must have existed, to the south of Nan-t'ou,[1] a more or less equatorially trending fold, which therefore stretched about vertically on the anticline of Nan-t'ou. The synclinal area, which, according to my view, and in connection with this fold, exists to the south of the Yang-tzï shows a continuous gorges-limestone formation, both near Sin-t'an with the steeply S-dipping fold of Lung-tchoe, and between the Lu-kan and I-ch'ang gorges. The anticlinal parts, which, in connection with the foregoing, must have existed to the north of the Yang-tzï have disappeared through erosion.

This continuation of the gorges-limestone formation overlying the granite south of the Yang-tzï is not reproduced on Willis' map.

Pumpelly, on the other hand, writes:

> In the immediate neighborhood of the river, over an area of forty or fifty square miles, the limestone has disappeared but, in the distance, on both sides of the Yang-tzï, its yellow cliffs are seen towering to a height of more than 2,000 feet above the water.

As far as the granite area extends, the course of the Yang-tzï shows, with regard to the anticlinal axis which must run through it, a typically symmetrical line, which consists of two, about equally long WNW–ESE pieces, connected by a bend toward the south. In the middle part of the granite area there occur many dykes trending about N–S of aplite, pegmatite and melaphyre, which have only been partly eroded in the river bed, thus leaving obstacles, which give rise to rapids.

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[1] On the map of my *Géologie du Bassin Rouge*, Nan-t'ou has not been given the right location as is also not the case in the map of Yi-tschang-fu (*Plankammer der Königl. Preuss. Landes*, Aufnahme), from which it was copied.

As I already found occasion to remark in my former publication, these dykes of eruptive matter in the granite and crystalline schists, I bring into genetical connection with the plication of the anticline of Nan-t'ou.

Just below Nan-t'ou finally begins the last or I-ch'ang gorge. Pumpelly[1] here mentions to the east of the granite area of Nan-t'ou, once more metamorphic strata and says: "Those to the eastward, which could not be closely examined, seemed to be gneiss trending E–W and dipping about 30° to S."

Blackwelder[2] relates the following about a formation named by him "the Nan-t'ou formation" which is indicated on Willis' map to the north of the Yang-tzï:

> On account of the absence of fossils the age of the Nan-t'ou formation is not accurately known. It lies at the base of the Cambro-Ordovician limestone from which we obtained lower and middle Cambrian fossils within less than 100 miles, 160 km., from Nan-t'ou. Hence it is highly probable that these glacial beds on the Yang-tzï are of early Cambrian age.
>
> Little is known at present regarding the areal distribution of the Nan-t'ou glacial beds. The horizon at which they occur is exposed many miles both north and south of the Yang-tzï, at the base of the escarpment which is crowned by the Cambro-Ordovician limestone; but the river crosses it at one point only and we had no other opportunity to see it. At the lower entrance to the Lu-kan gorge Pumpelly examined the base of the limestone system, and reported 50 feet, 15 m., of quartzite, overlain by limestones, which contain layers and lenticular masses of flint. It is probable therefore that the glacial beds do not occur in that locality.

I have not observed anything of all this, and only saw that the gorges-limestone rests direct on the granite which may eventually have become gneissy. "The glacial beds of early Cambrian age," I am, however, at a loss to reconcile with my own observations.

The first portion of the I-ch'ang gorge shows 10° SE-dipping layers, which the river crosses almost vertically. At the same place, where a diminution in the incline of the layers occur together with their more slaty condition, the Yang-tzï bends round to the SSW.

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[1] *Smithsonian Contributions to Knowledge*, Vol. XV, p. 4.

[2] *Research in China*, Vol. I, Part 1, p. 264.

In the Mi-t'an gorge we saw that this level of the gorges-limestone formation was steeply inclined, and on both sides of the river had been excavated into deeply grooved cross valleys. In the eastern limb of the Nan-t'ou anticline which has a much fainter dip, the river has completely altered its course, where it reached this softer level in the hard limestone formation. Afterward it again bends round to an ESE course, and cuts through ever-higher levels of the gorges-limestone formation, until, at the end of the I-ch'ang gorge, it makes a sharp curve to the south. In this latter part of the gorge occur many minor plications in the layers which, as a whole, continue to dip 10° SE. The limestone strata, gently sloping away, disappear under the I-ch'ang series.

Although I did not perceive it, Willis again assumed the existence of the Sin-t'an shale and the Ki-sin-ling limestone in the I-ch'ang gorge. He writes:

> The lowest or I-ch'ang gorge of the Yang-tzï is cut across the Wu-shan limestone which rises at the rate of about 1,000 feet a mile till the Sin-t'an (middle Paleozoic) shale appears from beneath it. Further upstream the Ki-sin-ling (Cambro-Ordovician) limestone forms a second gorge, and passing from a dip of 10° to a nearly horizontal position, gives rise to the mesa like heights above Huang-ling-miau.[1]

But the deep erosive valleys in the Sin-t'an shale altogether fail to prove that the above quoted view of the structure of the I-ch'ang gorge is correct. The photo published by me on p. 25 of my *Géologie du Bassin Rouge* shows high rising cliffs of limestone on the left side of the Yang-tzï, where, according to Willis, a deep erosive valley of Sin-t'an shale ought to exist. My photos on p. 28 sufficiently prove that Willis' idea, that the Ki-sin-ling limestone borders the right side of the Yang-tzï from Nan-t'ou till Huang-ling-miau, is not in accordance with the reality.

Below the I-ch'ang gorge the Yang-tzï enters upon its lower course, and, to far below I-tu, it cuts across a formation of sandstone and red argillite layers, which between I-ch'ang and I-tu are folded into a broad and flat anticline.

Blackwelder calls this "apparently a recurrence of the K'ui-chóu formation."[2]

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[1] *Research in China*, Vol. I, p. 286.

[2] *Op. cit.*, p. 287.

In the *Géologie du Bassin Rouge*, pp. 163, 164, I remarked concerning this:

> Although the formation of I-ch'ang misses the characteristic appearance of the K'ui-chóu formation, we may safely presume that both are of the same geological age, especially as concerns the formation of I-ch'ang and the upper levels of those of K'ui-chóu. In the syncline of Lao-k'ui-chóu we have observed similar red and white more or less sandy argillites and we might imagine that the coarser material was deposited in the Basin, while the finer matter was collected on the outside.

Finally I must still mention the occurrence of a thick conglomerate bed with pebbles of a size ranging from that of a marble to that of a fist and more, which is found on both sides of the river above the present water level, and which point to an old river formation. It therefore dates after the plication of the Red Basin, and has been formed by the action of the hydrographical system, which appeared after the plication.

According to my idea Pumpelly has wrongly interpreted the signification of the conglomerate layer. He writes:

> Near the city of I-ch'ang, at the eastern mouth of the gorge, the limestone strata, trending here NE and dipping about 80° to SE, are covered by apparently conformable beds of fine-grained gray sandstone, which toward the top soon merges into a coarse conglomerate. . . . . This conglomerate is followed by a red sandstone, which, above I-tu, dips easterly, and below that place westerly.[1]

Hence Pumpelly considers this conglomerate as a level in the I-ch'ang formation.

From K'ui-chóu to I-ch'ang, the Yang-tzï thus cuts through the high mountain ranges, here rising to 1,200 m, which form the boundary between the Red Basin of Ssï-ch'uan and the East China plain. The structure of these mountain ranges, may appear clear from the geological map and the different sketches. The deep gully, cut out by the Yang-tzï in these ranges exposes a succession of the finest and most interesting pictures of its inner structure. It is, as we see, a succession of folds, in which faults only play a secondary part.

The above suggests the following questions which I shall consider consecutively:

1. The tectonic signification of these folds.

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[1] *Smithsonian Contributions to Knowledge*, Vol. XV, "Geological Researches in China, Mongolia, and Japan," p. 7.

2. The signification of the anticline of Nan-t'ou.

3. The causes which have enabled the Yang-tzï to cut through these high-limit ranges.

Concerning the first point I must remark that the folds here are not sinial folds taken in the sense von Richthofen attached to old Paleozoic ENE–WNW trending folds, in North China (Liau-tung). The folds[1] of the Red Basin of Ssï-ch'uan are of much younger date, in fact, younger than the K'ui-chóu formation, which has been plicated together with the lower layers. The almost equatorial trend in the easterly border area of the Red Basin I have already explained through the deviation of these later folds against the so much older folded mountain ranges of the Tsin-ling-shan and Kuen-lun. In the *Monatsberichte* of the German Geological Society, No. 9, p. 202, I wrote:

> We can therefore describe that part of the earth's crust in southwest China in the following manner: Firstly, in the south a widely extending upheaval of the earth's crust in broad, flat folds; then, toward the north an increase in height and number of the regular and parallel folds; finally, the deviation of the whole series from the NNE–SSW direction, to an ENE–WSW and EW one, in consequence of the "Anschaarung" of this system of folds against the equatorially trending Kuen-lun or Tsin-ling-shan system.

Formerly I wrote concerning this:

> It is quite possible that this pressure will have left visible traces north of Wu-shan and K'ui-chóu-fu in this old mountain range (the Tsin-ling-shan).[2]

As a fact Willis, who passed through the land north of Wu-shan, along the Ta-ning-ho, gives, in his oft-mentioned work (pp. 288, 289) a section, which shows that the folds, from S to N, to the north of the Yang-tzï, become more and more sharp and high, while, finally, a little to the north of Sü-kia-pa, 65 km north of Wu-shan, he depicts a great overthrust, about which he writes (p. 291):

> Northward from Sü-kia-pa, there is, however, a complexity of structure which we did not fully understand in the field, but now interpret as an overthrust fault.

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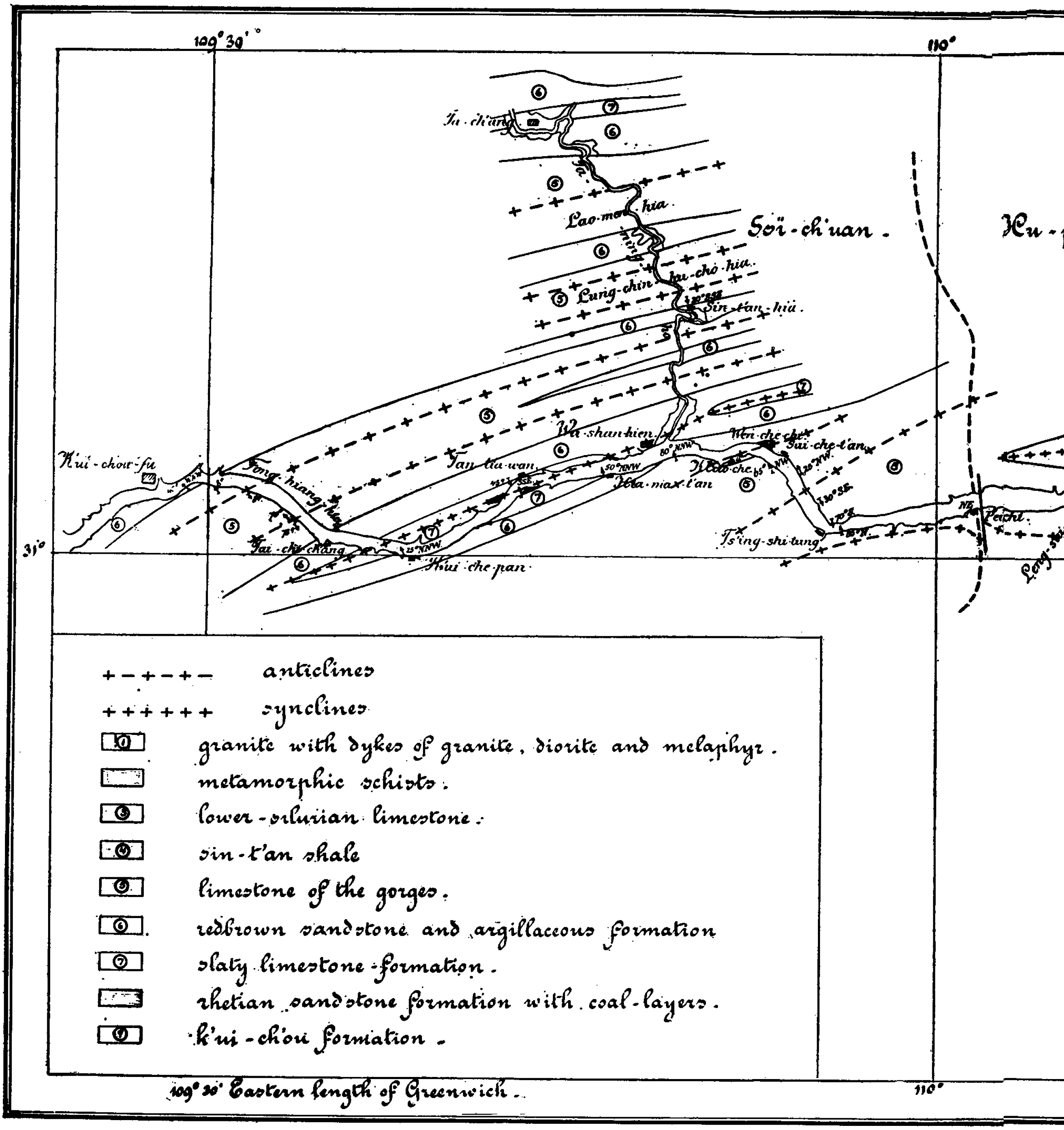
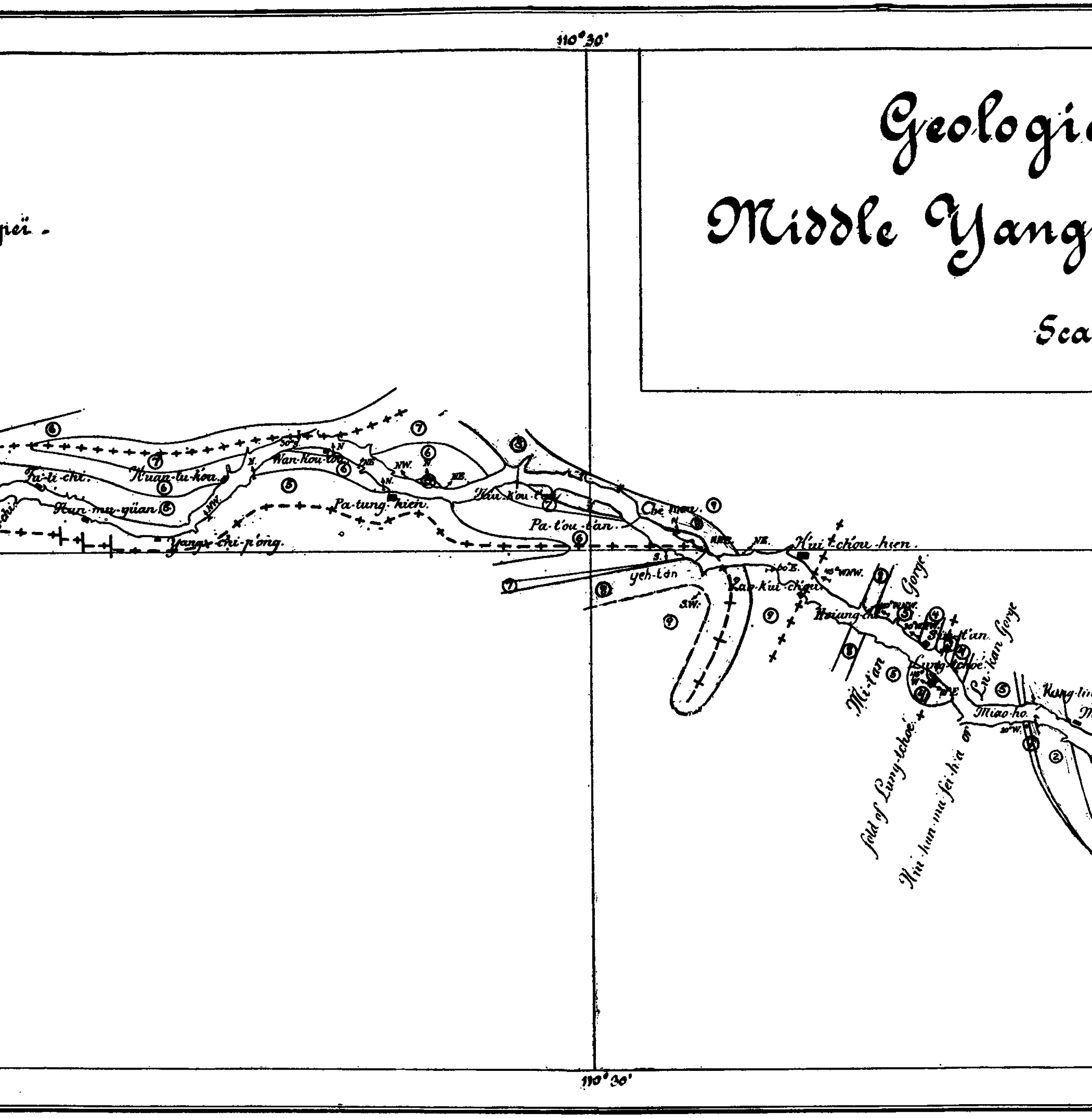
[1] Whether these folds are younger or older than those of the Jura mountains cannot be said for the present moment; but we may point out that they very materially output the latter as concerns regularity and simplicity.

[2] *Géologie du Bassin Rouge*, p. 181.


109° 30'
110°
31°
Soï-ch'uan.
Hu-
I-ch'ang
Lao-mou-hia
Lung-chin
Lu-chö-hia.
Sin-t'an-hiü.
Wu-shan-hien
Wu-che-che
Sui-che-t'an
Kui-chou-fu
Fong-hiang-hia
Tan-tia-wan
Hiao-che
Hia-ma-t'an
Tai-chi-chang
Kui-che-pan
Ts'ing-shi-tung
Peichi.
Long-
80° NNW
50° NNW
65° NNW
30° NNW
30° SE.
70° E
15° NNW
45° SSE.
NE
+ – + – + –   anticlines
+ + + + + +   synclines
①   granite with dykes of granite, diorite and melaphyr.
metamorphic schists.
③   lower-silurian limestone.
④   sin-t'an shale
⑤   limestone of the gorges.
⑥   redbrown sandstone and argillaceous formation
⑦   slaty limestone-formation.
rhetian sandstone formation with coal-layers.
⑨   k'ui-ch'ou formation.
109° 30' Eastern length of Greenwich.
110°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Geologi
Middle Yang
Sca
peï.
Tu-li-chi.
Kuan-tu-kou.
Han-mu-güan
Wan-Kou-tou
Pa-tung-hien.
Yangx-chi-p'ong.
Kiu-Kou-t'an
Pa-t'ou-t'an.
Che-men.
Kui-chou-hien.
yeh-t'an
Lao-kui-chou
Hsiung-che
Mi-t'an
Gorge
Lu-kan Gorge
Lung-tchoe
Miao-ho.
Kung-lin
fold of Lung-tchoe
Hui-kun-mu-fei-h'a or
N.
NW.
NE.
S.
SW.
30°E.
60°E.
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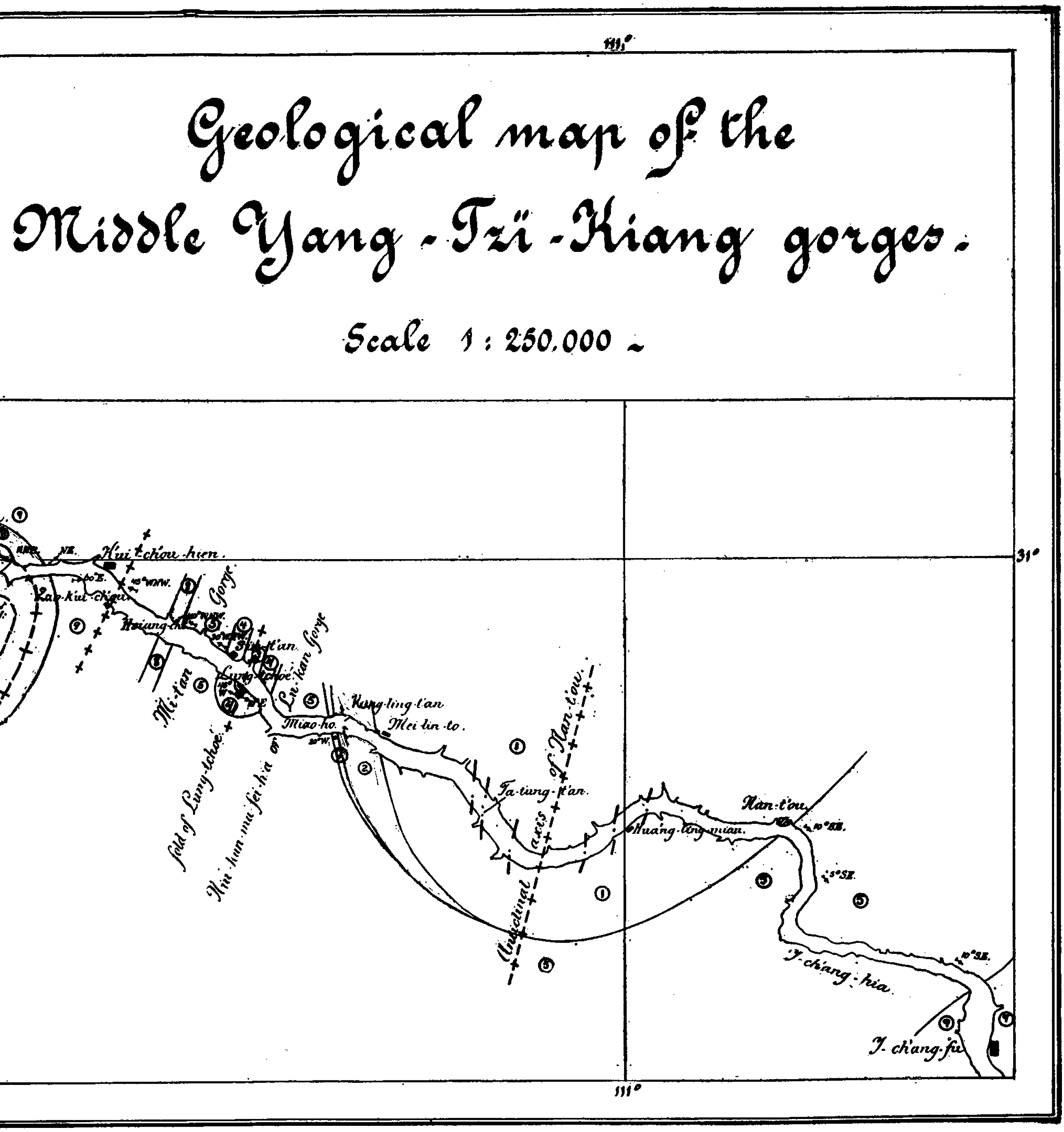
20°W.
110°30'



Geological map of the Middle Yang-Tzï-Kiang gorges.

Scale 1 : 250,000.

From the foregoing it is clear that I cannot agree with the views expressed by von Richthofen[1] in the following quotations:

> In this way it becomes plain that an immense area, situated to the south of the easterly Kuen-lun, whose basal structure in the parts known to us (and probably in its entirety), consists of the paleozoic formations, and which is folded together according to the sinial trend of the strata, can yet show great variety in its separate parts.

Although I fully agree with the description of the geological structure given in the next passage, I can by no means agree with the example von Richthofen adduces to illustrate the event of the welding together of the Kuen-lun mountains with the southern system of plication. On p. 638 we read:

> One of the most remarkable circumstances is the firmly growing together of the sinial zone of plication with that of the Kuen-lun in the Tsin-ling-shan. Just as when upon a cloth, folded into parallel folds, were laid a heavy bar at an oblique angle to the direction of those folds, and this bar were moved, at right angles, to its axis toward those folds until they were so bent round as to completely take the direction of the bar, in the same way the stiff stem of the Kuen-lun leans against the sinial folds. While at a distance from the Kuen-lun they strike from SW to NE, they gradually bend round toward the Kuen-lun, to a WSW–ENE trend. At the same time they press so closely, and the strata attain such a steep dip, that they become joined with the principal stem into one solid mass.[2]

From this example of the bar on the folded cloth we might draw the conclusion that von Richthofen assumes that the Kuen-lun mountains are of later formation than the area to the south of it, considered by him as occupied by mountain ranges folded up according to the sinial system. I need not reiterate what I wrote above, for I made it clear enough there that I believe the relation to have been exactly the contrary, namely: an older Kuen-lun range, against which the almost meridionally directed recent folds of the Red Basin struck —like the surf of the ocean beating against the firm land—thereby causing them to rise and to bend round, and thus to assume, only locally and incidentally, a trend in accordance with that of the sinial system of folding.

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[1] *China*, Vol. II, p. 637: "So erklärt es sich, dass ein ausserordentlich ausgedehntes, im Süden des östlichen Kwen-lun gelegenes Gebeit, dessen Grundbau in den uns bekannten Theilen, und wahrscheinlich in seiner Gesammtheit, aus paläozoischen Formationen besteht, und nach der sinischen Streichrichtung zusammen gefaltet ist, doch in seinen einzelnen Strecken grosze Verschiedenheit darbietet."

[2] *China*, Vol. II, p. 638: "Zu den bemerkenswerthesten Umständen gehört das feste Verwachsen der sinischen Faltungszonen mit denen des Kwen-lun im Tsin-ling-shan. Wie, wenn man einen schweren Stab auf ein in parallele Falten geworfenes Tuch unter schiefem Winkel zur Richtung dieser Falten legt und ihn gegen dieselben hin rechtwinklig zu seiner Axe fortscheibt, die Falten sich bis zur völligen Anschaarung umbiegen, so schmiegt sich der starre Stamm des Kwen-lun an die sinischen Falten. In grösserem Abstand von ihm von SW nach NO gerichtet, biegen sie an ihm zu einen WSW–ONO Streichen um! Zugleich drängen sie sich so dicht, und die Schichten nehmen eine so steile Stellung an, dass sie sich zu einer einzigen starren Masse mit dem Hauptstamm verbinden."

Another confirmation of my idea of the forcing-up of the Red Basin folds, as I was able to observe it in the northeastern parts, I find far to the westward, described in the following communication by von Richthofen:

> The outermost southern branch of the sinial system, which to the south of Kwang-yuen is still hidden under the formations of the Basin (see Fig. 111*c*) now appears in ever mightier lines, striking at first WSW and then SW, and forms (as beforesaid) the lofty northwestern wall of the plain of Tschöng-tu-fu. It here bears the name of San-miën-shan and Kiu-ting-shan.[1]

According to my opinion, the tension, which caused the Red Basin to be folded and to be pressed up against the Kuen-lun, became less in this westerly part, so that a basin fold still could be deviated by the Kuen-lun from its normal direction but at the same time (the fold) became flatter and vanished, instead of running high up against the Kuen-lun mountains, as is the case in the eastern part.

As concerns the signification of the Nan-t'ou anticline, we may conclude from the foregoing:

1. The crystalline schists are found to the west of the granite area of Nan-t'ou. Originally they will also probably have occurred to the east, but they are washed away, while sediments were deposited in a basin forming itself to the westward.

2. To the visibly oldest sediments belongs my lower Silurian brown limestone of Sin-t'an, with its fossils, the Cambro-Ordovician Ki-sin-ling limestone of Blackwelder and Willis. As we saw, this formation does not extend as far to the east as the lower entrance of the Ox-liver gorge. It does not seem to occur to the east of the Nan-t'ou anticline.

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[1] *China*, Vol. II, p. 639: "Der äusserste Südzweig des sinischen Systems, welcher nördlich von Kwang-yuen noch unter den Beckengebilden verschwindet (fig. 111*c*) hebt sich in seinen erst nach WSW, und dann nach SW gerichteten Streichen immer mächtiger hervor und bildet wie erwähnt, die erhabene Nordwestmauer der Ebene von Tschöng-tu-fu. Er führt hier die Namen San-miën-shan und Kiu-ting-shan."

3. In transgression for some kilometers toward the east we find my green shale formation, Blackwelder's middle Paleozoic Sin-t'an shale, which thins out not far to the east of Miao-ho at the lower entrance of the Ox-liver gorge. To the east of the Nan-t'ou anticline this formation does not seem to occur either.

4. To the Sin-t'an shale succeeds my gorges-limestone formation, Blackwelder's Upper Carboniferous Wu-shan limestone.

Now we see the remarkable fact that the Nan-t'ou area, which proved to be an eastern land-ridge for the older formation, becomes a sea, together with the eastern part, during the Upper Carboniferous period. *This sea very probably in transgression spread over a great part of China.* After the limestone formation the area of Nan-t'ou again resumes its rôle of boundary wall between an eastern and a western basin.

5. The (probably) Permian and Lower Triassic reddish-brown formation only occurs in an eastern part of the Red Basin, not in its center. It extends along the Yang-tzï as far downstream as Yeh-t'an, but not as far as Hsiang-chi.

6. The (probably) Upper Triassic slaty limestone formation extends even less far toward the east. It thins out already above Yeh-t'an. Neither of these formations occur to the east of the Nan-t'ou anticline.

7. Overlying this transgrades the Rhetian sandstone formation in the Red Basin itself far to the west. Although the area of Nan-t'ou is again a land limit against which the sandstone formation thins out, this same Rhetian sandstone, which contains coal measures, occurs in the East China Basin and also in other parts of China. We already noticed before that the formation itself extends farther east than the coal layers, which occur in higher levels.

8. This retrogression of the sediments westward is continued, and we find the shell-marl strata of probably Cretaceous age only in the middle of the Red Basin, whilst it thins out in more or less extensive lenticular layers between Wan-hien and K'ui-chóu-fu.

9. After this again comes a period of transgression. The K'ui-chóu formation extends to the western limb of the Nan-t'ou anticline. It seems that this anticline did not act as dividing line for the upper levels of this formation, for we find the I-ch'ang formation overlying its eastern limb, as far as it has not been washed away by ero-

sion. The very highest level which consists of very coarse-grained and micaceous sandstone, however, again only occurs in the center of the Red Basin.

In resuming the above we must come to the important conclusion that the area of Nan-t'ou must have played the part of a dividing line ever since the Cambro-Ordovician, or perhaps still earlier ages, until after the depositing of the K'ui-chóu formation (Cretaceous formation or later ?). During all that time, however, it twice gave up this rôle: once during the Upper Carboniferous and for a second time, let me say, during the upper K'ui-chóu time. At last the broad mighty anticline of Nan-t'ou was completely formed as we see it nowadays, partly destroyed by erosion.

The later formed folds of the Red Basin are therefore of younger date, and although we might assume an earlier date for the beginning of their growth, which a more careful research may possibly teach us from the trend of the extension of the reddish-brown and the slaty limestone formations, it must be inferred that their growth proper must have taken place much faster than that of the Nan-t'ou anticline.

As I already remarked above, these NNE–SSW folds of the Red Basin are bent up against the Tsin-ling-shan which I regarded as the consequence of the Red Basin having been pressed to the north.

Finally, I again refer to the deviation of the anticline of Pa-tung against that of Nan-t'ou, which fact agrees with the greater age and capacity of resistance of the latter.

And now I have still to consider the question of what were the reasons which caused the hydrographic system that originates nowadays on the eastern slope of the highlands of Tibet south of the Kuen-lun mountains, to force its way through the high mountain ranges from K'ui-chóu-fu to I-ch'ang. Until the present moment I have not fully considered this point. In the literature that I have consulted, on this subject I only find an explanation from Arthur Kniep[1] which, however, seems so strange to me that I shall not discuss it here.

[1] "Der Yang-tzĭ-kiang als Weg zwischen den Westlichen und Ostlichen China," *Gerlands Beiträge zur Geophysik*, Band VII, Heft I, pp. 22, 23. The explanation of

Of all the existing theories those of antecedent and regressed or beheaded rivers seem the most probable to me. Even in a developed and grand river system as that of the Yang-tzï-kiang it seems quite possible that both factors combined to produce such a system.

When we look at the map of China, we are impressed by the fact that the whole basin of the Upper and Middle Yang-tzï finds an outlet through the most northerly area which borders, to the south, the high dividing mountain range of north and south China. It readily appears to us that whilst the Kuen-lun is the divide between the Upper Yang-tzï and the Upper Hwang-ho, its eastern prolongation, the Tsin-lin-shan, remains the divide of a southerly developed Yang-tzï system and a northerly developed Hwang-ho system. Thus, in very general features, facts can be understood by a glance at the map.

But to return to the Middle Yang-tzï itself. We must first of all bear in mind that the anticlines of the Red Basin, and with them, of course, its entire area decline from N to S. This fact must be inferred from the observations that in consequence of an intensive erosion the anticlines in the northern parts of the Red Basin have been weathered away to a thickness of at least 2,500 m. down the gorges-limestone, which now still rises in mountains of 1,500 m. and more. These arch cores of limestone are only to half their height concealed under anticlinal limbs of the younger formations. More to the south the limestone cores have lowered to the level of the Yang-tzï and the cores of the sandstone formation, lying over the limestone, rise to anticlinal ridges of some 300 m., whilst there the overlying mighty K'ui-chóu formation has been washed away and has only remained in place in the synclinal areas, where it is dissected by numerous narrow cross and length valleys. At last, south of Ki-kiang, a place some 100 km. in right line south of Chung-king, I encountered an anticline which up to the height of 500 m. still consisted of the youngest or K'ui-chóu formation, the sandstone formation there being very much lower than it is in the country of Chung-king.

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the antecedent theory, to which I shall also appeal, seems to him very improbable. Kniep speaks of a peneplain between Wan-hien and I-ch'ang, where the Ta-kiang (a local name for this part of the Yang-tzï) should have taken its meandering course without close connection to the rock structure.

Thus, when we appeal to the antecedent theory we must accept the fact that this antecedent river not only had the power of cutting its course through a succession of parallel folds but even could keep the better of a general rising of the land contrary to its way from south to north, from far upstream Chung-king till Wan-hien. Nothing opposes itself to this combined movement of the earth's crust, viz., its being folded and at the same time pressed up against the Tsin-ling-shan; on the contrary the observations lead to this inference as is explained in the above. To account for the last-mentioned discrepancy we must suppose that the river had a sufficient power, as the result of a considerable fall anywhere in its course and that there was no possibility of going another way, for a river does its work only when it is forced to it. Now, it is almost certain that east of I-ch'ang, where nowadays still exists the low east China plain with its many lakes (Tung-ting, Po-yang, etc.,) ever since the filling up of the Red Basin there was a considerable difference in height from west to east. Might any obstruction have occurred in the antecedent river by the rising of the country from south to north, it still would be possible that a more intensive erosion in the watercourse took place from I-ch'ang in an upriver direction. But here we already appeal to the regression theory, for it may be that the rate of land-folding and uplifting have been the same as that of the cutting-power of the river water, or the first may have stopped the last till regression of the old watercourse redressed the former river-way, which then could continue its work in the old direction.

As to the second condition necessary for the absolute maintenance of the antecedent theory, viz., the impossibility for the river water of going another way, we cannot say very much because of the very incomplete geographical and geological investigations of southern China. When we look at the map we see that all great tributaries of the Yang-tzï, and its headwaters too, run in general lines from north to south. This makes me feel quite inclined to suppose that the hydrographical system of the province Ssï-ch'uan once must have found an outlet toward the south according to the general incline of the earth's surface from north to south. If this is true, then we must consider one or more of southwestern China's big rivers as beheaded ones by a retrogressed river system, which now is that of the Middle

Yang-tzï. That the effect of retrogression proved to be most powerful as near as possible to the Tsin-ling-shan appears most natural. The open sides of the Nan-t'ou and Sin-t'an areas toward the north quite accord with a retrogression theory for this last part of the Middle Yang-tzï.

All the grand gorges of the Middle Yang-tzï are very interesting when one could see in them the fixed image of the relation between the rate of movement of the earth's crust in the folding process and of the cutting-power of a river. Although from Chung-king to I-ch'ang the Yang-tzï cuts through the anticlinal mountain ranges nearly perpendicularly, there is a sufficient number of exceptions, for instance, where the river has a meandering course in the gorges; so from this point of view we cannot find either a proof to support the antecedent theory, nor one against it. The indifference of the Middle Yang-tzï to the general land-structure, rising from south to north, might account to the antecedent theory. On the other hand the bending round of the Yang-tzï, near Wan-hien, from a general NNE to an ENE course, in complete correspondence to the turn of the anticlines of the Red Basin against the Tsin-ling-shan, seems to bear against this theory, for here the river has followed the mountain structure. If there has been any antecedent watercourse in this region, it must anyhow have been considerably affected by the folding process, probably being restored only after a retrogression process of a watercourse more downstream from this point.

From the above it is clear that by reason of the present condition of the investigation of the whole of the Yang-tzï basin we cannot come to a decisive opinion to attribute the origin of the grand gorges of the Middle Yang-tzï-kiang either exclusively to the antecedent river theory or to that of the retrogression process.

Contrary to Kniep, however, I must point out that the meanders of the Yang-tzï in the synclinal valleys and even in the eastern limb of the Nan-t'ou anticline were exclusively caused by the geological and the rock structure. Another important example of this kind can be seen in the part of the river between Wan-hien and K'ui-chóu-fu, where the Yang-tzï, having lowered its course to one of the thick sandstone layers of the K'ui-chóu formation, here being in a horizontal position, has cut its way in a straight canal-like bed, obliged to do so by the rock structure.

The Middle Yang-tzï might be called a mature river, and this even after it has been revived, as seems to have been the case only once. The conglomerate bank of principally eruptive pebbles, mentioned above, shows the remains of the floor of a former Yang-tzï valley, in which the river has cut its narrower trench of nowadays. The mighty work here already accomplished by Nature has rendered the Yang-tzï navigable to far above Chung-king, thus making it for a length of more than 2,500 km. one of the most important highroads for traffic. That which Nature has left undone would be no serious obstacle for the amelioration of this waterway because the obstructions do not consist of falls, but only of rapids as the result of not-yet-washed-away detritus accumulations and partly uneroded dykes of eruptive rocks in the Nan-t'ou granite area. These obstructions, that make steam navigation on the Middle Yang-tzï not yet economically practicable, can, according to my idea, easily be overcome by human technics, and it is by no means beyond financial possibility. This has already been set forth in detail by me in an article, "La navigabilité du haut Yang-tzï-kiang par bateaux à vapeur," published in the *Revue universelle des Mines,* at Liège, tome XII, 4e série, p. 149.

No doubt the geology of the mountain ranges which are cut by the Yang-tzï between K'ui-chóu-fu and I-ch'ang still offer many interesting problems and points of view. But I believe to have given in the foregoing, in general features, the geological structure of this most interesting area as it appears in reality. Indeed, all that I saw of the Red Basin of Ssï-ch'uan and its border parts, leads me to the conviction, that, as for structural geology, this is one of the classic parts of the earth's crust, showing its inner and outer structure in a way to allow of the finest detail studies of folding and erosion, which appear in a pattern of the utmost simplicity and regularity.